Effects of Geometry on Speed–Flow Relationships for Two–Lane Single Carriageway Roads

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Abstract. Speed–flow relationship is usually used as a basis for the performance and capacity analysis of a highway segment. This paper presents the preliminary result of a study carried out to evaluate the effects of road geometry on speed–flow relationship for two–lane single carriageway roads. Speed and traffic volume data at five uninterrupted two–lane single carriageway road segments located in different parts of Malaysia were collected using an automatic traffic counter equipment. Result of the analysis shows that speed and traffic flow variables for a single carriageway road were linearly related. The percentage of no passing zone, road bendiness and hilliness, and the presence of minor junctions were found to have negative effects on the speed–flow curve. The speed–flow–geometry relationship developed in the study produces the estimates of travel speed higher than the values estimated using both USHCM and British models and lower than the MHCM’s model. However, more data representing large range of traffic conditions and roadway characteristics are required to enhance the accuracy of the speed–flow–geometry relationship developed in the study.

Introduction

Highway capacity is generally defined as “the maximum number of vehicles that can pass a given point during a specified period under prevailing roadway, traffic, and control condition” [1]. Theoretically, highway capacity is often derived from speed–flow–density relationships [2]. American Transportation Research Board (TRB) [3] suggested that capacity analysis is to be conducted for segments of a facility having uniform traffic, roadway, and control conditions. In practice, the overall level of service of a facility is based on the road segment with the poorest operating conditions.

Many reports, for instance as reported by Garber and Hoel [4] and Heydecker and Addison [5], indicate that the speed–flow–density relationships are in a parabolic form. However, the TRB’s speed–flow curve [1, 3] does not seem to fit the parabolic–formed of relationship. The speed–flow model developed for the Malaysian Highway Capacity Manual (MHCM 2011), on the other hand, is a linear–formed of relationship as shown in Fig. 1(a) [6]. The recent USHCM’s speed–flow relationship is also shown in Fig. 1(b) for comparison.

![Figure 1. Relationship between average travel speed and flow rate.](image-url)
It is interesting to note that the linear–formed of the speed–flow relationship suggested by the MHCM 2011 appears to support the findings of three major studies carried out in Great Britain in early 1970, 1980 and 1990, i.e. by Duncan [7], Transport and Road Research Laboratory [8, 9] and Lee and Brocklebank [10]. The speed–flow relationships developed by Lee and Brocklebank [10], which was adopted in the British Department of Transport’s economic assessment of road schemes software (COBA) [11], take account explicitly the effects of almost every aspects of road geometry including visibility and junctions.

This paper discusses the effects of road geometry on speed–flow relationships for Malaysian road traffic conditions.

Methodology

Site Selection

The survey sites were selected based on the following criteria [10, 12], i.e. (a) road segment is relatively homogeneous in geometric characteristics, (b) there is no major junction within the segment or within at least 1km of its endpoints, (c) there is no road works along the segment, and (d) the length of the road segment is more than 2 km.

The selection criteria defined above were adopted to ensure that there is no interruption on the speed behaviour and the motorist’s selected speed is in a stable condition. In this study, five uninterrupted two–lane single carriageway road segments were considered. The characteristics of the road segments considered in the study are tabulated in Table 1. The definitions of hilliness and bendiness are illustrated in Fig. 2. The average bendiness and average hilliness were calculated using Eq. 1 and Eq. 2.

Data Collection and Analysis Method

The speed and flow data was collected using an automatic traffic counter (ATC). An ATC was used because it allows traffic data to be collected for a long period of time.

For each site, the 24-hour speed and flow data was divided into a 15–minute interval dataset. A short interval observation will allow the analyst to capture various moments if there are any platooning situation occurred in the segment [2]. The flow rate was obtained by simply multiplying
the 15–minute traffic volume by 4 as suggested by TRB [1]. The average spot speeds or time-mean speeds were then converted to space mean speed using Eq. 3 [6, 12].

\[ u_s = 1.016u_t – 1.704 \]  

where \( u_s \) is space mean speed while \( u_t \) is time mean speed.

**Results and Discussion**

**Speed–Flow Relationship**

Ninety six sets speed–flow data were collected for each of the sites considered in the study. Fig. 3 shows the variations of speed–flow data for one of the road segments evaluated in the study. It can be seen that a negative linear form of relationship with a reasonable degree of correlation can be developed for the road segment. Such a speed–flow trend is consistent with the general understanding that speed decreases as traffic volume increases. The speed at which the trend line intercepts the vertical axis is normally referred to as the free–flow speed, \( U_f \), for the road segment considered. The free–flow speeds derived from this study were found to be consistent with the speed limits posted for the corresponding road segments.

![Figure 3. Scatter plot of speed–flow data for Site C/FT003/1A.](image)

**Effects of Geometry on Speed–Flow Relationship**

A regression analysis was performed to evaluate the effects of various aspects of road geometry on speed–flow relationship. The aspects considered in the analysis are the total width of the carriageway in meter (CWID), shoulder width in meter (SWID), verge width in meter (VERGE), % no passing zone (NPZ), bendiness in degree/km (BEND), hilliness in m/km (HILL), number of minor left (LJUNCT) and right junction (RJUNCT) per km, opposing flow in veh/h (OPFLOW) and proportion of heavy vehicles (PHV).

Analysis indicates that the CWID, SWID, VERGE, OPFLOW and PHV have no significant effect on the average speed of vehicles. This is probably because the variations in the width of the traffic lane, shoulder and verge of road segments considered in the study are not that significant. The insignificant influence of opposing flow on speed, on the other hand, is probably due to high percentage of non-overtaking sections along the roadways. The small amount of heavy good vehicles in the traffic streams, i.e. 1.8% to 5.1%, did not affect the overall travel speed of traffic. Therefore, these variables were excluded from the relationship. Finally, speed–flow–geometry relationship developed is as shown in Eq. 4.

\[ U = 128.01 – 0.02016 \times Q – 0.05442 \times NPZ – 0.2436 \times BEND – 0.02739 \times HILL \\
– 7.73957 \times LJUNCT – 11.6994 \times RJUNCT \]  

where \( U \) and \( Q \) are speed and flow, respectively. All other variables are as defined earlier.
The $R^2$–value for the relationship is 0.77, i.e. a value indicating a reasonably good relationship exists between speed and the various influencing factors considered in the analysis. The signs associated with each of the variables in Eq. 4 are consistent with what would be expected intuitively.

The constant in Eq. 4 can be interpreted as free flow speed and may be described as the mean desired speed. However, here constant includes road geometry related modifying factors and, the definition of desired speed needs to be re-considered. Desired speed may be defined as a driver’s desired speed on a level straight road in the absence of any impeding vehicles. This definition applies to the constants in Eq. 4. The actual driver’s desired speed can be taken as the basic desired speed modified by road geometry. This is obtained by an appropriate combination of the constant and road geometry related terms in the relationships such as found in Eq. 4.

To visualise a typical form of the speed–flow curve for a specified single carriageway section, the relationship given by Eq. 4 is plotted in Fig. 4. The speed–flow curves based on USHCM 2010 [1], MHCM 2011 [6] and Lee and Brocklebank [10] were also plotted for a comparison. The plots are based on the characteristics of road segment marked as J/J46/1A given in Table 2.

It can be seen from Fig. 4 that for a given traffic volume under stable flow conditions, both USHCM 2010 and British’s speed–flow curves predicted a much lower travel speeds compared with both the observed data and the model developed in this study. The observed data in general is scattered around the proposed model.

The MHCM 2011’s speed–flow relationship, on the other hand, predicts the estimates of travel speed which are relatively higher than the observed values and other models as can be seen in Fig. 4.

### Summary

This paper discusses the relationship between speed, flow and geometry for a two–lane single carriageway road based on a range of traffic flow and geometry conditions. The main findings of the study can be summarized as follows:

- A parabolic curve describing speed–flow relationship, as it is traditionally understood, is difficult to be developed because traffic flow breakdowns seldom occur under uninterrupted flow

### Table 2. Parameter for Site J/J46/1A.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane Width, Shoulder, Verge</td>
<td>7.0m, 1.0m, 3.0m</td>
</tr>
<tr>
<td>No Passing Zone</td>
<td>52.5%</td>
</tr>
<tr>
<td>Bendiness, Hilliness</td>
<td>71.34 degree/km, 20.93 m/km</td>
</tr>
<tr>
<td>No of Minor Left &amp; Right Junctions</td>
<td>1.38/km, 1.38/km</td>
</tr>
<tr>
<td>Proportion Heavy Vehicle</td>
<td>0.022</td>
</tr>
</tbody>
</table>
conditions. In fact, there is no published information about traffic operations in congested situations on, or at capacity of, single carriageway roads in Malaysia;

• Under stable flow conditions, the average speed of vehicles on a single carriageway road appear to be linearly related with traffic flow;
• No passing zone, the presence of minor junctions, bendiness and hilliness reduced the average speed of vehicles and hence affect the speed–flow curve for a single carriageway road; and
• Applicability of USHCM and existing MHCM to the analysis of speed–flow relationships and hence the capacity of single carriageway roads for Malaysian traffic conditions need further verifications.

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References